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THE RESPONSE OF AIRCRAFT CAMOUFLAGE LACQUERS TO THERMAL RADIATION. PART II. 6000 DEGREES K RADIATOR AND 800 FT/SEC AIR FLOW

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Three colors of each of two lacquers on aluminum panels were exposed to radiation simulating that from 100 KT and 1 MT weapons, while air at a velocity of 800 ft/sec flowed across the exposed surface of the panels. Differences in the response of the lacquer-color combinations were observed, temperatures at the rear surface of the panels were measured, and an expression relating response to weapon size was derived.

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THE RESPONSE OF AIRCRAFT CAMOUFLAGE TO THERMAL RADIATION

(II) 6000°K RADIATOR and 800 ft/sec AIR FLOW

by

Earl T. Waldron

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FOREWORD

At the request of the Directorate of Air Frame Subsystems Engineering, Wright-Patterson Air Force Base, a small wind-tunnel was coupled to the Natick Laboratories' solar furnace and studies conducted to determine the combined effects of intense thermal radiation and air flow upon the response of lacquers used to protect aluminum. These studies were conducted under U.S. Air Force MIPR A5-6-274 with Mr. Robert Mach, Wright-Patterson Air Force Base as Project Officer.

The author is indebted to Mr. Frederick Meers, NLABS, for his excellent photographic coverage of the studies, to the staff of the Pioneering Research Laboratory for their cooperation in these studies, and, in particular, to Mr. Walter Koza, NLABS, who did much of the experimental work and data processing.

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PART II: 6000°K RADIATOR AND 800 ft/sec AIR FLOW

1. INTRODUCTION

A requirement exists to determine the thermal characteristics of camouflage paints when exposed to pulses of thermal radiation. The requirement encompasses the onset of changes in paint characteristics, the time-temperature history of the rear surface of aluminum panels protected by the paints and photographic evidence of these changes. The characteristics are required for the following situations: (1) A 6000°K radiator and zero air flow, (2) A 6000°K radiator and an air flow of 800 ft/sec across the face of the sample, (3) A 3000°K radiator and zero air flow, (4) A 3000°K radiator and 800 ft/sec air flow. The non-nuclear device considered most suitable for generating the required information is the large solar furnace at U. S. Army Natick Laboratories. Accordingly, studies were initiated under Air Force MIPR AS-6-274. The results obtained under Phase 1 were reported.[1] The observations made under Phase 2, a 6000°K radiator and an air flow of approximately 800 ft/sec across the face of the panel are reported here.

2. DESCRIPTION OF THE WIND TUNNEL

A description of the solar furnace used in these studies was given previously.[1] In order to achieve the combined effect of intense thermal irradiation coupled with high velocity air flow across the face of the aluminum panel, a 0.8 Mach wind tunnel was installed at the NLABS solar furnace.

This unit consisted of an inlet duct, a test section with a 6 inch by 1 inch throat, and a diffuser coupled through an 8-inch ID plastic pipe to two series connected 15 HP, 3600 RPM blowers. A schematic of the wind tunnel installed within the elevated test chamber of the solar furnace is shown in Figure 1, while Figure 2 shows the wind tunnel's test section positioned in a plane normal to the optical axis of the furnace and at its focus.

The test section was constructed with both its front and rear walls removable; the front wall consisted of a steel frame to which a flat quartz window was clamped and sealed with a neoprene gasket. Positioned at the focus of the solar furnace, it served as an air tight wall of the wind tunnel while permitting radiation to fall upon the front surface of the test panels. These were installed in a recess in the removable rear wall, which was also sealed with a neoprene gasket and contained provisions for externally connecting the thermocouple attached to the rear surface of each panel. Prior to installation at NLABS, the wind tunnel was calibrated at the University of Dayton Research Institute.

WIND TUNNEL INSTALLATION
Natick Solar Furnace

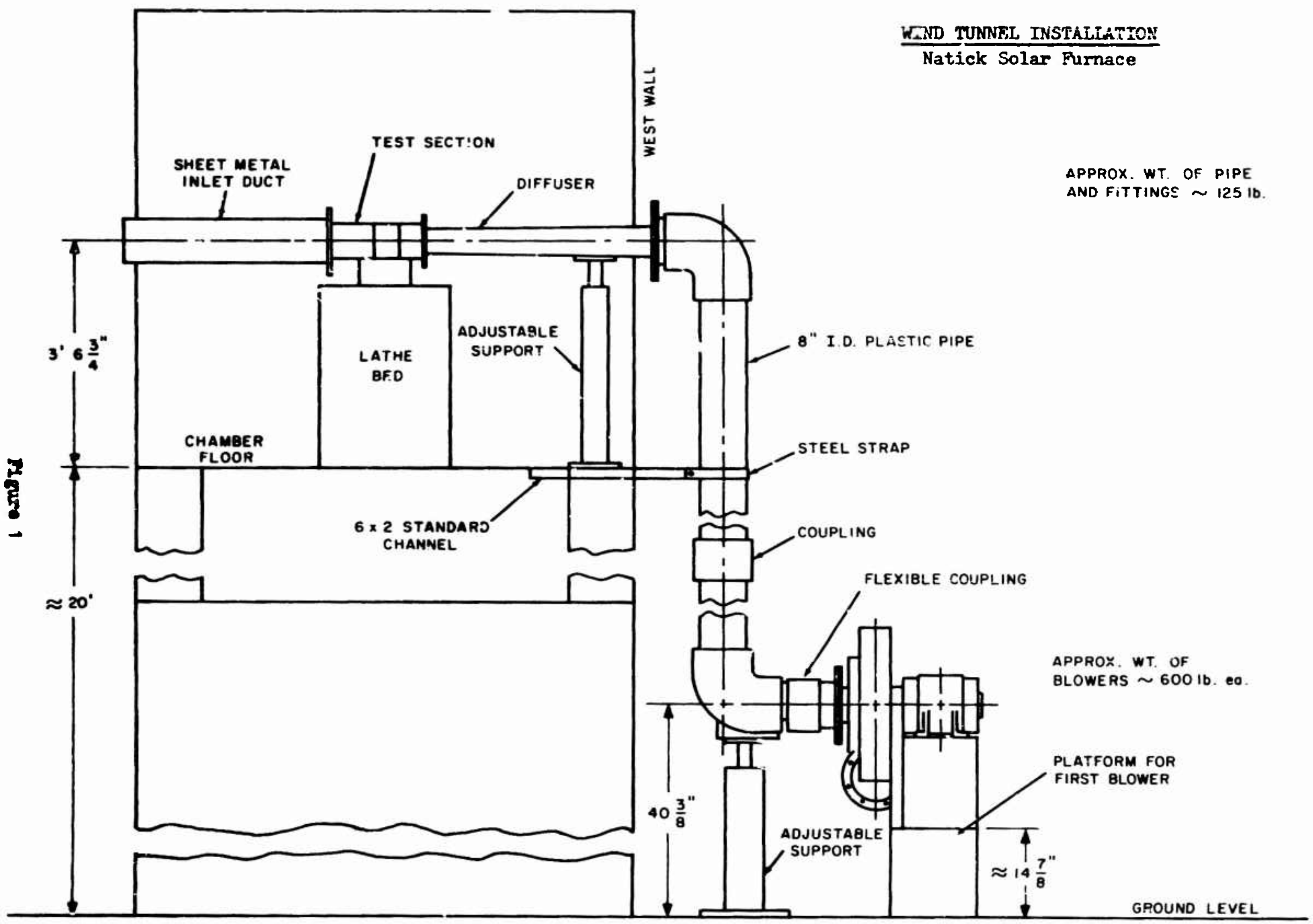

Figure 1

WIND TUNNEL INSTALLATION
Natick Solar Furnace
Top View

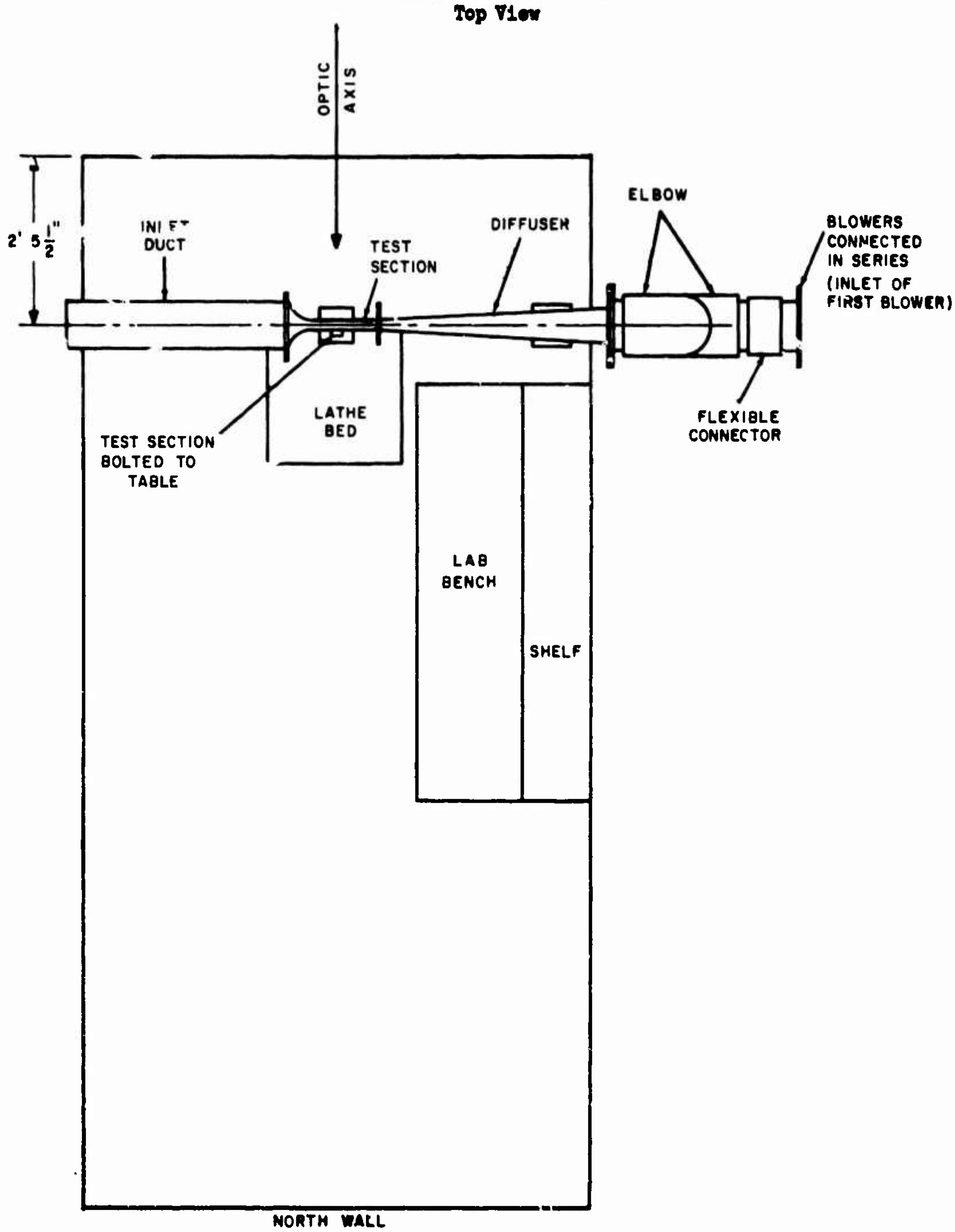

Figure 2

3. METHODS

A. Temperature Measurements at the Rear Surface of the Aluminum Panels.

As previously described, the removable rear wall of the throat was recessed to accept the test panel and grooved to permit attaching a thermocouple to the rear surface of the panel. With the panel and rear wall in place the front surface of the panel became an integral part of the inner face of the wind tunnel. Leads from the thermocouple were led through a cold junction to a Sanborn Model 151 recorder, to permit recording the time-temperature history of the rear surface.

B. Combined Effects.

Prior to exposing each aluminum panel, a radiation calorimeter was positioned in the plane to be occupied by the panel (rear wall of the test section removed) and the radiance measured. With the panel then sealed into place, the air flow through the wind tunnel was permitted to stabilize and the solar furnace activated. A pulse of radiant energy, simulating either the 100 Kt or 1 Mt weapon, was then imposed upon the front surface of the aluminum test panel and its rear surface time-temperature history recorded.

C. Photographic Technique.

In order to obtain a visual record of each panel's response within the wind tunnel, a four-inch diameter mirror was positioned concentric to the optical axis, facing the quartz front surface of the wind tunnel and approximately two feet from it. A camera positioned behind the rear wall of the wind tunnel was then able to photograph the sequence of thermal events within the tunnel.

4. DESCRIPTION OF THE PANELS

Test panels consisted of 5-inch squares of type 7075 aluminum, .03 inches thick. These were painted either green (light and dark), tan, or grey with either acrylic or acrylic-nitrocellulose lacquer. The specifications for the lacquers together with the absorptivity * of each color are given in Table 1.

The data of Table 1 show minor differences in the absorptivity of the dark and light green colors of each type of lacquer. This equivalence in absorptivity resulted in overlapping of the temperature data for these colors; hence these data were combined and the average value used in computations.

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* Measured with an integrating spectophotometer.[2]

TABLE 1

Color and Absorptivity of the Lacquers

Color	Acrylic Lacquer MIL-L-81352 (WP) (% Absorbed)	Acrylic-Nitrocellulose Lacquer, MIL-L-19538B(ASG) (% Absorbed)
Dark Green	93	92
Light Green	91	90
Tan	79	78
Grey	43	49

TABLE 2

Max. Rear Surface Temperature of Vari-Colored Aluminum Panels, - Combined 100 KT Thermal Pulse and 800 ft/sec Air Velocity - °F (°C)

Radiance Cals/cm^2	Dark Green (81352)	Lt.Green (81352)	Tan (81352)	Grey (81352)	Dark Green (19538)	Lt Green (19538)	Tan (19538)	Grey (19538)
12.4	277	258	240	162	277	258	221	141
19.4	402				351/365			
19.7		365	339			357	295	
20.7						382		
22.4				267			[illegible]	276
23.8			417		442	422		
24.5	456	458						
29.2	498					459		
31.1			450	298	552		412	313
34.8	627	604	531	358	591	576	486	362
41.8			608					
43.7				408			631	410
47.4				435				439

TABLE 3

Max. Rear Surface Temperature of Vari-Colored Aluminum Panels - Combined 1 MT Thermal Pulse and 800 ft/sec Air Velocity °F (°C)

Radiance cals/cm^2	Dark Green (81352)	Lt.Green (81352)	Tan (81352)	Grey (81352)	Dark Green (81352)	Lt.Green (81352)	Tan (81352)	Grey (81352)
20.7	302				284			
21.2	302	320	275		289	280	255	
28.3							318	
29.3	419	392	353		396	387	348	
35.0		433			404			
37.3	452		385		465			
38.7			414			462	420	
39.2	459							
42.4		491						
44.7	509/504				523			
46.6					536			
46.9			478	311				
47.3	553				525	5[illegible]7		353
48.7		558	511	350		536/537	485	358
53.5	631	604	545	352	548	555	508	393
56.5		652/630	567	394	619	621	534	405
61.1				390			576	417
74.5			684	412			660	473
80.4				443				467
88				439				495
99.5				488				
102				498				552

5. **RESULTS**

A. Temperatures measured at the rear surface of the aluminum panels.

Peak temperatures recorded at the cited radiances are given in Tables 2 and 3, while the equations for the regression curves derived from these data by standard statistical techniques are given in Table 4 and graphed in Figures 3 and 4. In both instances the lacquers are identified by their specification numbers, i.e., 81352 or 19538.

TABLE 4

The Relatedness Between Radiance, Q ($cals/cm^2$) and Peak Temperatures(T)°F Observed at the Rear Surface of Aluminum Panels Painted the Cited Colors

	Simulated 100 KT Thermal Pulse
Green (81352)	$T = 82.9 + 15.1\ Q$
Green (19538)	$T = 83.7 + 14.3\ Q$
Tan (81352)	$T = 85.7 + 12.6\ Q$
Grey (81352)	$T = 62.3 + 12.3\ Q$
Grey (19538)	$T = 68.0 + 8.0\ Q$
	Simulated 1 MT Thermal Pulse
Green (81352)	$T = 82.5 + 10.8\ Q - .019Q^2$
Green (19538)	$T = 67.3 + 11.6\ Q - .038Q^2$
Tan (81352)	$T = 71.5 + 9.8\ Q - .02Q^2$
Tan (19538)	$T = 70.1 + 9.7\ Q - .024Q^2$
Grey (81352)	$T = 131.6 + 3.8\ Q$
Grey (19538)	$T = 122.9 + 4.5\ Q$

The curves of Figure 3 indicate for the 100 KT pulse a slight superiority for the green and tan colors of lacquer 19538 and an equivalence between the grey lacquers. Less difference is observed between the green and tan lacquers exposed to the 1 MT pulse (Figure 4) while the curves infer a slight superiority to the grey colored lacquer 81352. The equations for the grey lacquers exposed to the 1 MT pulse indicate an unacceptable level of accuracy when the curves are extrapolated to zero radiance. This is undoubtedly due to the lack of data at radiances less than 47.3 $cals/cm^2$. The curves were thus terminated at this radiance.

B. Damage to the Lacquers.

The lack of similarity in the response of the lacquers precluded the use of a damage criterion based solely upon the onset of blistering, since this characteristic varied in size, depth of craters, and profusion. Rather it was decided to compare lacquers based upon an area of damage typical of each lacquer-color-radiance situation. Thus each lacquer-color combination was judged for effectiveness at that radiance which produced a clearly defined

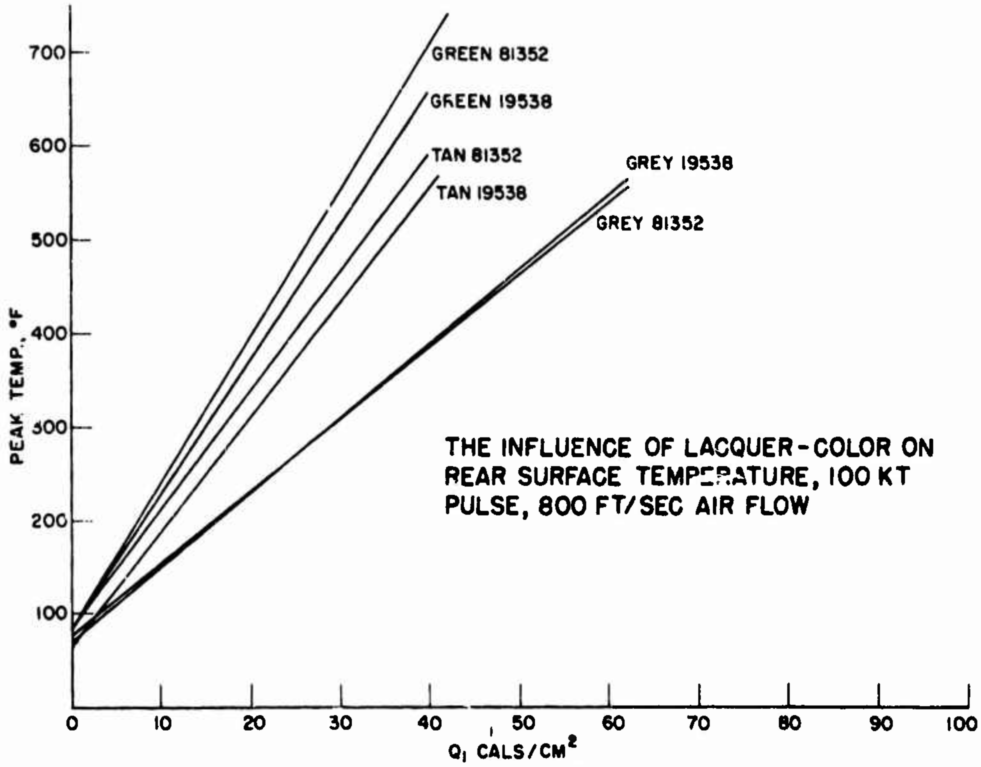

Figure 3

THE INFLUENCE OF LACQUER-COLOR ON REAR SURFACE TEMPERATURE, IMT PULSE, 800 FT/SEC AIR FLOW

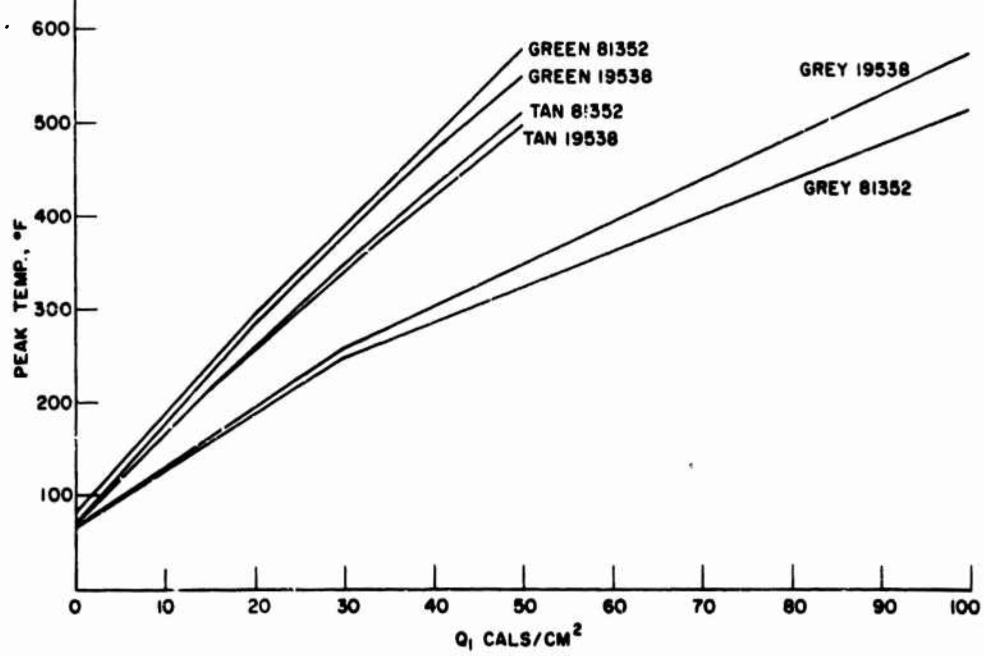

Figure 4

area of damage two inches in diameter. In those instances where blistering was apparent, the two-inch diameter area of damage corresponded to the onset of crater formation. This response was observed with Lacquer 81352. In contrast, the response of lacquer 19538 was a clearly defined two-inch diameter area wherein volatilization of the pigments had evidently occurred, leaving a discolored but relatively smooth surface.

The various lacquer-color combinations were judged by this criterion, and the radiance, for each weapon size, at which typical damage occurred over a two-inch diameter area is listed in Table 5 and graphed against weapon size in Figures 5 and 6. From these data, the constants a and b in the equation, $Q = AW^b$, where Q = radiance, cals/cm^2, and W = weapon size in kilotons, were determined and are given in Table 6.

TABLE 5

Radiance (q, cals/cm^2) Required to Produce Equal Areas of Damage

Color	MIL SPEC 81352		MIL SPEC 19538	
	100 KT Pulse	1 MT Pulse	100 KT Pulse	1 MT Pulse
Green	26.5	39.5	27.6	42.5
Tan	31.5	46.0	34.5	49.0
Grey	55.0	96.0	56.5	79.0

TABLE 6

Damage Equations for Areas of Damage

Color	MIL SPEC 81352	MIL SPEC 19538
Green	$Q = 11.8W^{.18}$	$Q = 11.5W^{.19}$
Tan	$Q = 14.8W^{.16}$	$Q = 15.6W^{.17}$
Grey	$Q = 18.5W^{.24}$	$Q = 28.9W^{.15}$

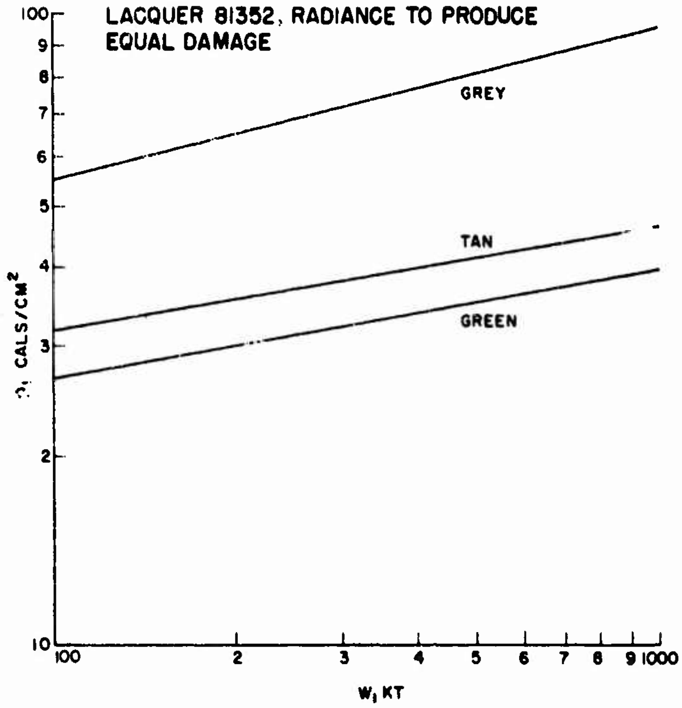

Figure 5

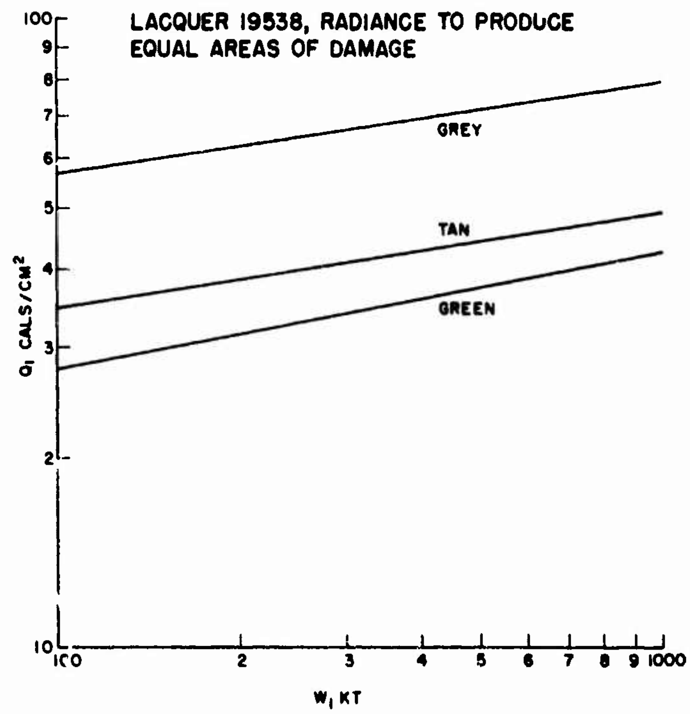

Figure 6

C. Rear Surface Temperature Corresponding to Front Surface Damage.

The rear surface temperatures calculated from the equations of Table 4 and the radiance required to produce equal areas of damage are listed in Table 7. The mean temperature for both the 100 KT and 1 MT situations was 489°F as compared to 487°F previously determined for the static situation. The rear surface temperature thus provides a quantitative criterion for comparing the influence of the lacquers, with the mean of the static and in flight situations being 487°F, (253°C)

TABLE 7

Rear Surface Temperatures
(100 KT Simulated Pulse)

Color	Q $cals/cm^2$	T (°F) MIL 61352	(°C)	Q $cals/cm^2$	T (°F) MIL 19538	(°C)
Green	26.5	483	(250)	27.5	477	(247)
Tan	31.5	483	(250)	34.5	487	(253)
Grey	55.0	498	(259)	56.5	520	(271)
		1 MT Simulated Pulse				
Green	39.5	480	(249)	42.5	492	(256)
Tan	46.0	480	(249)	49.0	488	(253.5)
Grey	96.0	496	(258)	79.0	478	(248)

D. Energy Absorbed by the Aluminum Panels.

The energy absorbed by each lacquer covered panel, based upon initial absorptivity, was calculated from the radiance required to produce a rear surface temperature of 488°F. These data are given in Table 8 and indicate an equivalence in energy absorbed by each lacquer for each weapon size. The data suggest the thermal response of the lacquer covered panels is more sensitive to the initial optical properties than to chemical formulation, although lacquer 19538 appears to offer some advantage when exposed to the 100 KT pulse.

TABLE 8

Energy (cals/cm^2) Required to Produce a Rear Surface Temperature of 489°F (255°C)

Color	Lacquer 81352		Lacquer 19538	
	100 KT	1 MT	100 KT	1 MT
Green	24.4	36.3	25.1	38.7
Tan	24.9	36.3	26.9	38.2
Grey	23.7	41.3	27.7	38.7
Avg.	24.3	38.0	26.5	38.5

A statistical test of the significance of the data of Table 8 is given in Table 9 and indicates an equivalence between the lacquers exposed to the 1 MT simulant. At the .05 level of significance, lacquer 19538 requires a slightly greater absorption of energy to produce a rear surface temperature of 489°F (°C) when exposed to the 100 KT pulse. Similar behavior at this weapon size was previously reported.

TABLE 9

"t" Tests of the Energy Required to Produce 489°F(255°C)

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	"t" Test
Between Cols.	1	(2) 1777.1	490.5	2.65
2 and 4		(4) 2120.9	695.4	
3 and 5	1	(3) 4341.1 (5) 4454.6	1440.9 1482.5	0.33

E. The Influence of Air Flow on the Rear Surface Temperature.

In Table 10, the radiance required at equivalent rear surface temperatures is compared for both the static and in-flight situations. The comparison is expressed as the ratio of radiance at an air flow of 800 ft/sec. (QW) to that at zero air flow (Q_o) and indicates that the average energy requirements for the in-flight situation are greater by factors of 1.83 to 2.03. If the atypical ratio for the grey lacquer (81352) is excluded *, an average ratio of 1.85 is indicated.

* 1 MT Pulse.

TABLE 10

Radiance (Q, cals/cm^2) Required to Produce
Rear Surface Temperatures of Approx. 488°F.(253°C)

100 KT Pulse

Wind Vel. =	Zero		800 ft/sec	Zero		800 ft/sec
	Lacquer 81352				Lacquer 19538	
	Q_o	Qw	QW/Q_o	Q_o	Qw	QW/Q_o
Green	14.5	26.5	1.83	15.5	27.6	1.78
Tan	17.0	31.5	1.85	19.0	34.5	1.82
Grey	30.0	55.0	1.83	30.0	56.5	1.88
			1 MT Pulse			
Green	21.5	39.5	1.84	21.0	42.5	2.02
Tan	25.0	46.0	1.84	25.0	49.0	1.82
Grey	38.0	96.0	2.53	40.0	79.0	1.88

Avg of Qw/Qo = 2.03

6. CONCLUSIONS.

a. An average rear surface temperature of 488°F(253°C) can be used to characterize the relative effectiveness of lacquers used on .03 inch thick type 7075 aluminum.

b. Damage to the lacquers for the in-flight situation parallels that for the static situation.

c. For both lacquers the energy required to produce equivalent rear surface temperatures increases with weapon size. The relatedness can be expressed by the relationship $Q = aw^b$ where Q equals radiance and W equals weapon size.

d. The response of the lacquer covered panels is dependent primarily upon the initial optical properties of the lacquers.

e. At a nominal air flow across the panels of 800 ft/sec, 1.85 times more energy is required for an equivalent damage temperature than is required for zero air flow.

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